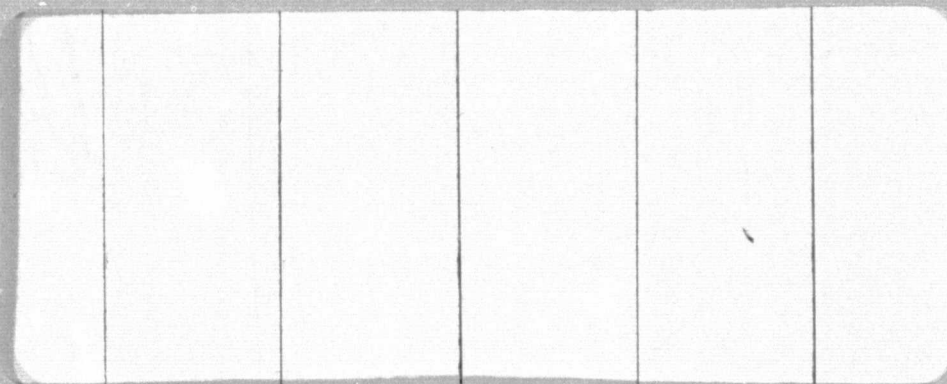


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THE AEROSPACE CORPORATION

(NASA-CR-146086) SHUTTLE USER ANALYSIS  
(STUDY 2.2). VOLUME 3: BUSINESS RISK AND  
VALUE OF OPERATIONS IN SPACE (BRAVO). PART  
5: ANALYSIS OF GSFC EARTH OBSERVATION  
SATELLITE (EOS) SYSTEM (Aerospace Corp., El

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SHUTTLE USER ANALYSIS (STUDY 2.2)

FINAL REPORT

Volume III: Business Risk and Value of Operations  
In Space (BRAVO)

Part 5: Analysis of GSFC Earth Observation  
Satellite (EOS) System Mission Model  
Using BRAVO Techniques

Prepared by

Advanced Mission Analysis Directorate  
Advanced Orbital Systems Division

28 February 1975

Systems Engineering Operations  
THE AEROSPACE CORPORATION  
El Segundo, California

Prepared for

OFFICE OF MANNED SPACE FLIGHT  
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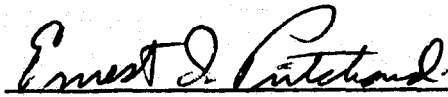
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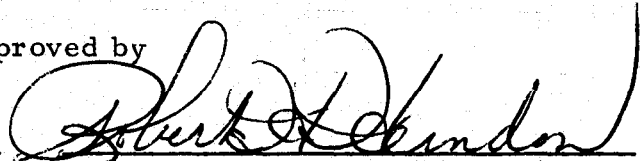
SHUTTLE USER ANALYSIS (STUDY 2.2) FINAL REPORT

Volume III: Business Risk and Value of Operations In Space  
(BRAVO)

Part 5: Analysis of GSFC Earth Observation Satellite (EOS)  
System Mission Model Using BRAVO Techniques

Approved by

  
Ernest I. Pritchard  
Study 2.2 Director  
Advanced Mission Analysis  
Directorate

  
Robert H. Herndon, Group Director  
Advanced Mission Analysis Directorate  
Advanced Orbital Systems Division

## FOREWORD

The Shuttle User Analysis (Study 2.2) Final Report is comprised of four volumes, which are titled as follows:

- Volume I - Executive Summary
- Volume II - User Charge Analysis
- Volume III - Business Risk and Value of Operations In Space (BRAVO)
  - Part 1 - Summary
  - Part 2 - User's Manual
  - Part 3 - Workbook
  - Part 4 - Computer Programs and Data Look-Up
  - Part 5 - Analysis of GSFC Earth Observation Satellite (EOS) System Mission Model Using BRAVO Techniques
- Volume IV - Standardized Subsystem Modules Analysis

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The Aerospace Corporation effort on this add-on task for Study 2.2 was supported by the following members of the technical staff:

### Earth Observation Mission Equipment and Problem Definition

T. Shiokari

### Launch Vehicle Accommodation Analysis

J. A. Plough

### Satellite Synthesis

R. T. Blake

### Cost Estimating

H. G. Campbell  
D. W. Cochran

### System Risk Analysis

J. J. Dawson

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## 1. INTRODUCTION

Under the Business Risk and Value of Operations In Space (BRAVO) task for Study 2.2, an analysis was initiated in July of 1974 and completed the end of August of 1974 which resulted in cost comparisons between three modes of operation for the Earth Observation System (EOS-B). This analysis was initiated at the direction of William F. Moore at NASA Headquarters for the purpose of comparing results with the Goddard Space Flight Center (GSFC)-sponsored EOS satellite contractor studies now in progress. The objective of this brief task was to make a comparison with the output of the contractor studies as a check on the validity of the BRAVO techniques. As this work was in progress, Mr. Frank Cepollina, GSFC, requested an expansion of the effort to consider additional cases designed to investigate the best way to operate the EOS systems with the Space Shuttle system considering cost analysis of an entire series of five projects (EOS-B, -C, -D, -E, and Solar Maximum Mission, SMM). An additional \$20K was contracted for this effort.

This add-on effort made use of the July/August 1974 results but superseded them with changes in satellite requirements, mission equipment, and population on orbit. This report describes the BRAVO/EOS add-on analysis.

The objective of the BRAVO/EOS analysis was to furnish data to NASA on alternative ways to use the Shuttle/EOS, thereby assisting NASA in selecting the best way to operate the EOS with the Shuttle. In this study, the space system mission capabilities between systems to be compared are made equal by utilizing identical mission equipment

in the same orbits for the systems compared. The space system risk (or outage) is made as nearly equal as possible between systems being compared by first, calculating the outage, and then by adjusting it as necessary. The method used most commonly to adjust outage is to change the number of spare satellites available for satellite replacement from the ground. For instance, if a satellite system shows an outage too low, the number of spares on the ground may be increased in order to lower the probability of a failure on orbit with no ground spare or replacement. With the space system mission capabilities and outage equal, then the space system costs can be compared one system to another with the confidence that one is comparing equal systems.

## 2. DEFINITION OF TERMS

### 1. SPACEFRAME

The spaceframe portion of the satellite includes structure and cabling which supports the satellite modules.

### 2. NON-REPLACEABLE UNIT (NRU)

The NRU portion of the satellite includes the spaceframe, the added flexible solar cell array, and any mission equipment which is not modularized.

### 3. SATELLITE MODULES

The satellite modules each generally contain an entire subsystem or major portion thereof in accordance with GSFC's module design approach for EOS. A module is designed for each of the following subsystems:

- a. Communications, Data Processing, and Instrumentation (CDPI)
- b. Guidance, Navigation, Stability and Control (GNS&C)
- c. Electrical
- d. Propulsion (including reaction control propellants)
- e. Modularized Mission Equipment

### 4. NON-STANDARD

A non-standard module design is sized and developed to meet the requirements for each specific mission.

5. STANDARD

Standard modules indicates that the modules are developed and applied to as many missions as possible. Under ideal conditions, one set of modules would be applied to all missions.

6. COST TO ESTABLISH AND OPERATE

The cost to establish and operate includes investment, transportation, launch operations, and satellite refurbishment or repair costs. It excludes DDT&E costs.

7. AVAILABILITY

Availability is the system up time divided by the up time plus the down time.

8. MODE OF OPERATION

The term mode of operation designates the approach to logistics supporting a satellite system during the operating period.

The modes considered in this analysis were space resupply mode, ground refurbishment mode, and expend mode.

9. SPACE RESUPPLY MODE

In space resupply, the primary mode for extending the operating life of a system when a failure is encountered, is to replace the failed module on orbit and return the failed module for refurbishment and reuse. Worn out or wearing out modules are also replaced on orbit by adding replacement modules to the failed modules flights. For a redundant component design, when a redundant component fails, the module containing the redundant failed component is replaced by adding modules to failed module flights. In addition, the failing modules with

a redundant component out may occasionally add up to a full load of modules for one flight, in which case they are replaced. In a space resupply mode it is possible to have a failure in a non-replaceable unit, in which case the satellite is replaced and returned to the ground for refurbishment. At this time any worn out modules or wearing out modules would also be replaced.

10. GROUND REFURBISHMENT MODE

For the ground refurbishment mode, the satellite on orbit is replaced by the spare satellite on the ground, usually a refurbished satellite. Six months is allowed for satellite refurbishment between the time the satellite is returned and is again ready for flight.

11. EXPEND MODE

For the expend mode, new satellites are used to replace failed satellites on orbit. It is assumed that the new satellites will be procured in advance of the need for replacement so that no procurement delays are encountered.

## SUMMARY

The satellite optimized in this analysis considering all five missions (EOS-B, -C, -D, -E, and SMM) was a design built up from standard subsystem modules with one level of component redundancy designed for four-year life considering expandable exhaustion and wear-out (resulting in approximately 28 months mean mission duration). The non-replaceable unit used the same basic spaceframe design for all five missions with special structure and cabling added when the number of modules reported exceeded six or when unique structure was needed to support non-modularized mission equipment. As is shown in later sections of this report, the standardization reduces the DDT&E costs substantially. For these analyses, it was assumed that the same NASA organization managed the standardized satellite development, procurement, and integration using the same contractor setup for each spacecraft development and fabrication. The long life reduces logistics costs for all three modes studied.

The results of the analysis comparing the three logistic modes (expend, ground refurbish, and space resupply) are summarized in Table 3-1 for the EOS satellites. The savings for the space resupply mode of operation over the other two modes of operation are the result of first a reduction in the number of flights and second a reduction in the amount of hardware, either purchased new or refurbished. For EOS-C, -D, and -E, the number of satellite flights is approximately the same for all modes of operation and the cost reduction for ground refurbishment over the expendable mode is due to the reuse of satellites after refurbishment. A further reduction in costs for the space resupply mode over the ground refurbished mode of operation is due to the reduction in the amount of hardware refurbished. In the space resupply mode, only a portion of the satellite is returned for refurbishment whereas in the ground refurbished mode the whole satellite is returned to the ground and refurbished.

Table 3-1. Comparison of Satellite System Modes of Operation  
STS Supported, Standardized Satellites with Redundant  
Components

Satellite Project	Satellite Operational Mode	System Availability	Number Of Satellite Launches	Cost To Establish & Operate Relative To Expendable Mode
EOS -B	Expend	0.90	9.4	1.00
	Ground Refurb.	0.86	9.3	0.76
	Space Resupply	0.92	6.6	0.57
EOS -C	Expend	0.92	5.7	1.00
	Ground Refurb.	0.90	5.6	0.74
	Space Resupply	0.90	6.5	0.65
EOS -D	Expend	0.86	10.7	1.00
	Ground Refurb.	0.79	10.4	0.71
	Space Resupply	0.83	10.8	0.63
EOS -E	Expend	0.88	10.0	1.00
	Ground Refurb.	0.85	9.9	0.83
	Space Resupply	0.84	11.0	0.63

#### 4. PROBLEM STATEMENT

The inputs and definition of the problem for the BRAVO/EOS satellite analysis are based on data furnished by GSFC or extracted from reference information made available by GSFC. These are the basic data around which the satellite was designed and operated in order to fulfill the five missions analyzed.

##### 4.1 SATELLITE SYSTEM OBJECTIVE

To use in the optimum way the Space Shuttle with EOS satellite configurations, before 1982 the EOS is launched by an expendable launch vehicle. In 1982 and after, the EOS is launched by and serviced by the Shuttle. The EOS configuration shall use standard housekeeping subsystem modules and shall accommodate sensors for earth observation of land resources, ocean dynamics, and atmospheric conditions. The tradeoff analysis shall consider Thor/Delta and Titan III expendable launch vehicles, and the deployment, on-orbit maintenance, and ground refurbishment modes of Shuttle operation.

The EOS missions to be addressed in this study are scheduled in Table 4-1. The missions which have an impact on the EOS system are the EOS-A, -B, -C, -D, and -E series. The SEOS, SMM, and EGRET missions are included for potential sharing of development and unit costs. The EOS series are all low-altitude and polar-inclined missions, but have specific equatorial crossing times. The equatorial crossing times will require the Shuttle to perform orbital inclination change operations when servicing more than one satellite.

Table 4-1. EOS Satellites On Orbit Schedule

Missions	Orbit (nmi x deg)	Equator x Time	Mission Equipment	Expendable Shuttle															
				Launch Vehicle															
				77	78	79	80	81	82	83	84	85	86	87	88	89	90		
EROS																			
EOS-A	385 x 98.2	11:00AM	MSS + TM*			1	1												
EOS-B	385 x 98.2	11:00AM (2)	TM + HRPI + DCS					1	2	△	2	2	2	△	2	2	2		
Water Res., Poll- ution & Commodity Prediction																			
EOS-C	385 x 98.2	9:30AM 3:30PM	[TM + HRPI*+ SAR*] [POLL. MONT.*(3)]				1	1	1	1	△	1	1	1	△	1	1		
Ocean Dynamics																			
EOS-D	430 x 108°	(1)	[ALT*, SCAT*, SAR*, MWR*, VIRR*]	1	1		△	2	2	2	△	2	2	2	△	2			
Weather & Climate																			
EOS-E	450 x 98.8	9:00AM 3:00PM	[VTS, AVHRR, DCS, SEMS, CZACS]			1	2		2	2	2	2	△	2	2	2	△		
SEOS (Synch. EOS)	Geosynch.	NA	[1.5M Telescope/ Image*]							1	1	△	1	1	1	△	1	1	
Scientific																			
SMM (Solar Max. Mission)	300 x 28	NA	[11 Sensors*, Mag. - Spect.]			1	1	△	1	1	1	△	1	1	1	△	1		
EGRET (Expl. Gamma Expt. Telescope)	250 x 28	NA	Spark Chamber*				1	1	1										

**NOTE:**

- \* Mission Equipment DDT&E for First Flight  
 △ Mission Equipment DDT&E  
 NA Not Applicable  
 (1) Two Satellites are Phased  
 (2) Two Satellites Phased 180° Apart  
 (3) Pollution Monitor Assumed to be Similar to TM

The NASA Headquarters Office of Manned Space Flight (OMSF) interest in sponsoring this effort was to parallel the GSFC contracted studies on EOS. For OMSF, satellite designs, analysis, cost studies, and comparisons were made on EOS-A and EOS-B as the contractors were doing.

GSFC was interested in a more complete analysis and comparison, involving all EOS missions and, in addition to the BRAVO synthesized EOS system, operating BRAVO on the contractor-generated design.

#### 4.2 SATELLITE MISSION EQUIPMENT

- a. Type: Earth Observations
- b. Description: Summarized in Table 4-2 and detailed in Tables 4-3 and 4-4. For completeness, the SMM mission description is described in Table 4-5.

#### 4.3 SATELLITE INTERFACES WITH EARTH SURFACE

- a. Low rate telemetry, command, and tracking functions with existing STDN stations.
- b. Wideband communication (200 Mbps) link to Sioux Falls, South Dakota will provide CONUS coverage (station does not currently exist).
- c. Low cost ground stations (20 Mbps) for user direct access of selected mission equipment data with minimal ground equipment investment.

#### 4.4 YEAR REQUIRED, GROWTH

- a. Initial Operation: 1978
- b. Full Operation: 1982
- c. Growth Rate: None

Table 4-2. Summary of EOS Satellites Mission Equipments

EOS	MISSION EQUIPMENT <sup>(1)</sup>	MISSION EQUIPMENT			WIDE BAND COMMUNICATION SYSTEM				
		Point Acc.	Average Power W	Weight kg (lb)	Data Rate Raw (Proc) <sup>(2)</sup> Mbps	Tape Recorder Weight kg (lb)	Power W	Transmission Unit Weight kg (lb)	Coverage
A	MSS + TM	30 Sec	100	215 (474)	115	-0-	175	55 (120)	CONUS
B	TM + HRPI + DCS	30 Sec	124	314 (691)	175	-0-	230	73 (160)	CONUS
C	2TM + HRPI + SAR	30 Sec	1329 <sup>(3)</sup>	572 (1261)	475 <sup>(4)</sup>	182 (400)	300	91 (200)	CONUS
D	ALT + SCAT + SAR + MWR + VIRR	0.5 Deg	506	360 (794)	25 (0.350)	91 (200)	140	36 ( 80)	WORLD-WIDE
E	VTs+AVHRR+DCS + SEMS + CZACS	0.2 Deg	340	364 (800)	(0.323)	45 (100)	120	36 ( 80)	WORLD-WIDE

- (1) For further detail on mission equipment characteristics, see Tables 4-3 and 4-4.
- (2) Processed data transmission rate shown in parenthesis; no raw data transmitted when processed data transmitted.
- (3) 1150 Watts operates only during daylight hours for 10 minutes/orbit.
- (4) 275 Mbps transmitted; 200 Mbps stored on tape.

**Table 4-3. Mission Equipment**

Mission Equipment	5-Band Multi-Spectral Scanner (MSS)	Thematic Mapper (TM)	High Resolution Pointable Imager (HR PI)	Synthetic Aperture Radar (SAR)
Sensor	Multi-Spectral Scanner	Scanning Spectro Radiometer	Pointable Multi-Spectral Scanner	Radar 1 Band
Measurement Frequency	0.5 - 12.6 $\mu$ m 5 Bands	0.5 - 12.6 $\mu$ m 7 Bands	0.5 - 1.1 $\mu$ m 4 Bands	8.5 GHz Single Frequency
Swath Width	185 km	185 km	48 km	40 km
FOV, Deg.	11.5	15	$\pm 40$	2
Resolution	86 $\mu$ rad	30 $\mu$ rad	14 $\mu$ rad	30 $\mu$ rad
Data Rate: Unprocessed Processed	15 Mbps	100 Mbps	75 Mbps	2-100 Mbps
Size: Optics Unit	9 Inches 0.4 x 0.4 x 1 m	16 Inches 1 x 1.1 x 1.3 m	16 Inches 1 x 1.1 x 1.3 m	4.5 x 0.8 m NA
Average Power, W	45	55	69	1150 <sup>(1)</sup>
Reliability	NA	90% @ 2 Yr.	90% @ 2 Yr.	95% @ 100 Hrs.
Stabilization Axis	3-Axis	3-Axis	3-Axis	3-Axis
Pointing: Direction Accuracy	Earth $\pm 0.7$ deg. <sup>(2)</sup>	Earth $\pm 0.01$ deg.	Earth $\pm 0.01$ deg.	Earth $\pm 0.01$ deg.
Weight: Optics Assembly Electronics	65 kg	150 kg	150 kg	40 kg 82 kg
Reference <sup>(3)</sup>	4.9 b	4.9 c	4.9 d	4.9 e

(1) Operates only 10 minutes per orbit.

(2) ERTS pointing requirements.

(3) Indicates reference listed in Section 4.9, page 4-9, of this report.

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**Table 4-4. Mission Equipment**

Mission Equipment	Ocean Topography Altimeter (ALT)	Wind Field Scatterometer (SCAT)	Coherent Imaging Radar (SAR)	Microwave Radiometer (MWR)	Visible And Infrared Radiometer (VIRR)
Sensor	Pulse Radar	Active Fan Beam	Synthetic Radar	Microwave Scanner	Visible and Infrared Scanner
Measurement Frequency	13.6 GHz	14.5 GHz	1.376 GHz	6.6 - 37 GHz 5 Bands	0.5 - 12.5 $\mu$ 2 Bands
Swath Width	1.2 km	$\pm 49$ deg.	2 - 100 km	1000 km	1900 km
FOV, Deg.	1.5	0.5	20	1.2	0.4
Resolution: Accuracy Area	$\pm 0.5$ m 20 km	$\pm 20$ deg. 50 km	25 m 100 km	$\pm 0.5$ deg. 100 km	2 km 2 km
Data Rate: Unprocessed Processed	7.0 Kbps 0.4 Kbps	240 bps 240 bps	25 Mbps 350 Kbps	4 Kbps 1 Kbps	12 Kbps 3 Kbps
Size (Optics)	1 - 1.0 m Parabola Dish	5 - 2.7 m Sticks	2 - 4.5 x 2.5 m Panels	1 - 1.25 m Off- set Parabola	12 cm Mirror
Average Power, W	125	107	184	65	25
Reliability	NA	NA	NA	NA	NA
Stabilization Axis	Pitch & Roll	Pitch & Roll	3-Axis	3-Axis	3-Axis
Pointing: Direction Accuracy	Nadir $\pm 0.75^\circ$	Nadir $\pm 1.0^\circ$	$\pm 20^\circ$ of Nadir $\pm 0.5^\circ$	Nadir $\pm 1.0^\circ$	Nadir $\pm 0.5^\circ$
Weight: Optics Assembly Electronics	5 kg 40 kg	35 kg 40 kg	100 kg 75 kg	50 kg	10 kg
Reference <sup>(1)</sup>	9 f	9 f	9 f	9 f	9 f

(1) Indicates reference listed in Section 4.9, page 4-9, of this report.

Table 4-5. Summary of SMM Satellite Mission Equipments<sup>(1)</sup>

Mission Equipment	Pointing Accuracy <sup>(2)</sup>	Average Power (W)	Weight		Data Rate (bps)	Coverage (deg)
			kg	(lb)		
UV Magnetograph	5 sec.	20	45	(99)	500	2
EUV Spectrometer	5 sec.	20	45	(99)	1000	2
X-Ray Spectrometer	5 sec.	15	45	(99)	350	5
X-Ray Imaging	10 sec.	15	45	(99)	200	5
X-Ray Polarimeter	1 sec.	10	7	(15)	400	5
Gamma Ray Detector	1 deg.	12	90	(198)	500	20
Hard X-Ray Spectrometer	1 deg.	12	32	(71)	500	20
Solid State X-Ray Detector	1 deg.	5	9	(20)	200	10
Coronagraph	2 min.	10	45	(99)	500	20
UV Spectrometer	5 sec.	20	50	(110)	500	2
Neutron Detector	1 deg.	15	93	(205)	200	20
H-Photometer	5 sec.	10	9	(20)	125	2
Flare Finder	10 sec.	10	14	(31)	50	2
Summary	1 sec.	174	529	(1165)	5025 <sup>(4)</sup>	--

(1) Candidate payload instruments for initial SMM (see section 4.9, reference k).

(2) Pointing accuracy assumed equivalent to sensor alignment accuracy.

(3) Nighttime power requirements approximately 20 percent of average power.

(4) Data rates will double during flare activity for one minute duration.

#### 4.5

#### PREFERRED SPACE SYSTEM APPROACH

- a. Sun synchronous inclination and altitude consistent with ground resolution; direct CONUS communication and low program cost.
- b. Standardized spacecraft modules to accommodate land resource management, water resource and pollution monitoring, ocean dynamic measurements, and weather and climate observation. The spacecraft design should have flexibility for missions not yet defined. The satellite on-orbit operational control is located at Greenbelt, Maryland for telemetry, tracking, and command via S-band link to STDN stations. The mission equipment data are transmitted to Sioux Falls, South Dakota for direct CONUS link and lower rate data to many user stations that are equipped with low cost ground systems (LCGS). The basic capabilities of the LCGS are to display image data and produce photo products.
- c. System should provide 70 to 80 percent on-orbit time coverage.
- d. Share deployment and service operation with other missions to reduce cost.

#### 4.6

#### COMPETING TERRESTRIAL SYSTEMS

Not to be studied.

#### 4.7

#### SYSTEM BUDGET

None provided.

#### 4.8

#### SPECIAL PROBLEMS

- a. Advanced state-of-the-art:
  - (1) Data transmission rates of 200 Mbps. Current space and ground equipments do not have this capability.
  - (2) Airborne tape recorders of 200 Mbps.
  - (3) Standard spacecraft subsystem modules.
- b. Optimize Shuttle parking orbit.

#### 4.9

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- i. Earth Observatory Satellite System Definition Study (EOS), Reports 1, 2, and 3, 22296-6001-RV-0, TRW, 15 July 1974.
- j. Earth Observatory Satellite System Definition Study, Report 3, Design Tradeoff Studies and Recommendations, GE Space Division, 15 July 1974.
- k. Solar Maximum Mission (SMM) Conceptual Study Report, X-703-74-42, NASA/GSFC, January 1974.

In order to carry out the intent of the problem statement, alternative systems and satellite characteristics were defined. Satellites were synthesized, their costs estimated, and the risks assessed for each of the alternative approaches. The result of considering the alternatives, then, was to obtain tradeoff data which was used to select

the optimum or lowest cost approach. Alternative satellite characteristics that were used in the analysis (in addition to varying the mode of operation) were:

1. Standard and non-standard satellite subsystems
2. Satellites designed with nominally no component redundancy (except for critical path for satellite operation which would prevent satellite retrieval) and nominally one level of component redundancy
3. Satellite-furnished velocity for deployment and placement in final orbit. Propulsive  $\Delta V$  capabilities of 0, 304.8, and 457.2 m/sec (0, 1000, and 1500 ft/sec) were used. For no propulsive capability, the Shuttle deployed the satellite in its final orbit and retrieved or serviced satellites in their final orbit. For propulsive capability of 304.8 m/sec (1000 ft/sec), the orbiter deployed the satellite in an elliptical orbit with perigee of 185 km (100 nmi) and apogee at the circular altitude of the final orbit. Retrieval or service is performed in the same elliptical orbit. For propulsive capability of 457.2 m/sec (1500 ft/sec), the satellite was deployed in a 296 km (160 nmi) circular orbit by the Shuttle. Satellite retrieval or service were performed in the same orbit.

## 5. SATELLITE SYNTHESIS

Satellite design synthesis for the EOS system for non-standard spacecraft is a straightforward application of the BRAVO Satellite Synthesis Computer Program described in Reference 11.1 (Section 11). The inputs and outputs to the analysis are contained in the BRAVO/EOS Workbooks on file at Aerospace Corporation. The mission equipment and its characteristics used in the synthesis are described in the problem statement (see previous section). The syntheses performed in July and August of 1974 specified satellite 95 percent power down while operating on the dark side. At the direction of NASA, the satellites were resynthesized in late September and October 1974 to obtain 100 percent operation (no power down) on the dark side. Although non-modular satellites were synthesized using the BRAVO techniques, all satellites actually analyzed for cost and logistics traffic were constructed of subsystem modules similar to those designed for the EOS by GSFC.

The synthesis of spacecraft with standardized modules is not currently an automated capability in the BRAVO techniques. The steps used in building up satellite designs for the EOS satellites from standard subsystem modules, including the selection of module size for standardization, are described in the following paragraphs.

The first step in the procedure is to select and synthesize non-standard but modularized spacecraft. For this analysis, the EOS-B and the EOS-C were selected as spacecraft designs whose modules would be good candidates for potential standardization and application to all five missions [EOS-A, -B, -C, -D, -E, and Solar Maximum Mission (SMM)]. The EOS-C was chosen because it was the heaviest

and highest performance spacecraft, therefore, the EOS-C modules could satisfy any of the other missions. At the same time it was recognized that the overkill of using all EOS-C modules for standardization would be extremely large. Therefore, a lower performing, lighter spacecraft set of modules (EOS-B) was selected which appeared to have application to many of the missions at a lower value of overkill. Once these modular spacecraft were synthesized, the design weight statement was reorganized so that the weights could be listed by module and spaceframe elements for all the EOS-B (small) modules and for the EOS-C (large) modules. Examples of these reorganized design weight statements are shown in Tables 5-1 and 5-2. The tables shown are for modules designed to obtain one level of redundancy at 100 percent power in the earth's shadow. The EOS-C design weight statement is for a satellite sized for a  $\Delta V$  of 304.8 m/sec (1000 ft/sec). The propellant for both the propulsion module and the reaction control system is hydrazine. The EOS-B was designed for no satellite propulsive capability. The other variables were the same as for the EOS-C.

The next step in the process of building up satellite designs from a standard EOS subsystem module was to select which modules were to be standardized. For each subsystem, both the EOS-B and EOS-C modules were considered by building up EOS-A, -B, -C, -D, -E, and SMM from each set of modules. Then either the EOS-B module or EOS-C module for each specific subsystem was chosen on the basis of:

1. Feasibility
2. Number of programs to which a module is applicable
3. Minimization of overkill.

For instance, the propulsive  $\Delta V$  module for the EOS-C was chosen on the basis of feasibility in that the normal mode of operation was expected to require a  $\Delta V$  of about 304.8 m/sec (1000 ft/sec). The EOS-C propulsion

Table 5-1. EOS-C\* Design Weight Statement Organized by Module

Unit	Weight	
	kg	(lb)
<b>Non-Replaceable Unit (NRU)</b>		
Structure and TPS	445	(980)
Solar Arrays	84	(186)
Distribution	44	( 97)
Power Conditioning	17	( 38)
NRU Total	590	(1301)
<b>Guid., Nav., and Stab.</b>		
Structure	31	( 68)
G.N. & Stab.	191	(421)
Elect. Dist.	48	(106)
G. & N. SRU Total	270	(595)
<b>Propulsion Module</b>		
Structure	103	(226)
$\Delta V$ Motor	136	(300)
$\Delta V$ Propellant	545	(1201)
RCS Inerts	30	( 66)
RCS Propellant	70	(154)
Elect. Dist.	8	( 17)
Propulsion SRU Total	892	(1964)
<b>CDPI Module</b>		
Structure	31	( 68)
CDPI	35	( 77)
Tape Recorders	242	(533)
Wide Band Comm.	121	(266)
Elect. Dist.	100	(222)
CDPI Total	529	(1166)
<b>Electrical Module</b>		
Structure	31	( 68)
Batteries	270	(596)
Elect. Dist.	68	(150)
Elect. SRU Total	369	(814)

\* For one level of redundancy.

Table 5-1. EOS-C\* Design Weight Statement Organized by Module (Cont'd)

Unit	Weight	
	kg	(lb)
<b>Thematic Mapper Module</b>		
Structure	31	( 68)
Thematic Mapper	180	(397)
Elect. Dist.	45	(100)
Thematic Mapper Total	256	(565)
<b>Pollution Monitor Module</b>		
Structure	31	( 68)
Pollution Monitor	180	(397)
Elect. Dist.	45	(100)
Pollution Monitor Total	256	(565)
<b>HRPI Module</b>		
Structure	31	( 68)
HRPI	180	(397)
Elect. Dist.	45	(100)
HRPI Total	256	(565)
<b>SAR Module</b>		
Structure	31	( 68)
SAR	146	(322)
Elect. Dist.	37	( 81)
SAR Total	214	(471)
<b>Wet Weight</b>	3632	(8006)
Adapter	123	(272)
<b>Gross Weight</b>	3755	(8278)

\* For one level of redundancy.

**Table 5-2. EOS-B\* Design Weight Statement Organized by Module**

Unit	Weight	
	kg	(lb)
<b>Non-Replaceable Unit</b>		
Structure and TPS	108	(237)
Elect. Arrays	25	( 56)
Distribution	23	( 50)
Power Conditioning	11	( 25)
NRU Total	167	(368)
<b>Guid., Nav., and Stab.</b>		
Structure	19	( 42)
G.N. & Stab.	113	(248)
Elect. Dist. & Condit.	32	( 71)
G. & N. Mod. Total	164	(361)
<b>Propulsion Module</b>		
Structure	19	( 42)
Propulsion	---	---
Apogee Motor	---	---
Apogee Propellant	---	---
RCS Inerts	14	( 30)
RCS Propellant	30	( 67)
Elect. Dist. & Cond.	4	( 9)
Propulsion Mod. Total	67	(148)
<b>CDPI Module</b>		
Structure	19	( 42)
CDPI	35	( 77)
DCS	12	( 27)
Wide Band Comm.	97	(213)
Elect. Dist. & Condit.	47	(104)
CDPI Mod. Total	210	(463)

\* For one level of redundancy.

Table 5-2. EOS-B\* Design Weight Statement Organized by Module (Cont'd)

Unit	Weight	
	kg	(lb)
<b>Electrical Module</b>		
Structure	19	( 42)
Batteries	81	(179)
Elect. Dist. & Condit.	24	( 52)
Elect. Mod. Total	124	(273)
<b>Thematic Mapper Module</b>		
Structure	19	( 42)
Thematic Mapper	179	(396)
Elect. Dist. & Condit.	52	(114)
Thematic Mapper Mod. Total	250	(552)
<b>HR PI Module</b>		
Structure	19	( 42)
HR PI	179	(396)
Elect. Dist. & Condit.	52	(114)
HR PI Module Total	250	(552)
<b>Wet Weight</b>	1232	(2717)
Adapter	78	(171)
<b>Launch Weight</b>	1310	(2888)

\* For one level of redundancy.

module could supply this capability for all satellites and have propellant off-loaded for many of the applications, thus minimizing overkill. Several missions required wideband data systems and a data recording capability so that the EOS-C CDPI (Communications, Data Processing and Instrumentation) subsystem was chosen for standardization. When not required, the system wideband data system was recovered from the CDPI module. The EOS-C basic spaceframe was selected as a basic or standard spaceframe. The basic spaceframe, which was common to all six satellite designs, provided for six modules. Additional spaceframes could be added for up to a total of eleven modules (as required for the EOS-C standardized design). The solar array is mounted directly to the spaceframe. For standardized solar array this is acceptable because the array is considerably oversized for all missions except EOS-C. Therefore, the life of the solar array could be extended by allowance for degradation in the solar cell output beyond normal tolerances.

EOS-B modules were selected for the remaining subsystems (guidance, navigation, stability and control; electrical power; thematic mapper; and high resolution pointing instrument). For guidance, navigation, stability and control and electrical power, the minimum number of modules applied to any design was one, however, several modules were used in satellite designs requiring increased performance from these subsystems.

Once these standardized modules were selected, the next step in the procedure was to build up each satellite design from a standardized module with the selected spaceframe approach and make an estimate of additional non-standard design weights. The total weight of each of the standardized satellite designs can then be calculated.

The last step in this synthesis of standardized spacecraft is to organize the standardized satellite design data into a format suitable for input into the cost estimating analysis. For this step, the subsystem weights are separated for each design; for each subsystem the weights are separated into standard and non-standard elements. The number of modules in each design is listed along with the number of common programs for each standard portion of satellite designs for each subsystem. The results of this step are illustrated by the data in Table 5-3. This example is again for the spacecraft with a propulsive  $\Delta V$  capability of approximately 304.8 m/sec (1000 ft/sec) and designed with one level of component redundancy in each of the subsystems.

The overkill resulting from this design approach is shown in Table 5-4. With further effort, the overkill could be reduced but this is not expected to have a large effect on the cost results.

Table 5-3. Design Weight Statement Organized for Cost Estimating EOS Spacecraft Build Up From Standard Modules

SPACECRAFT	EOS-A		EOS-B		EOS-C		EOS-D		EOS-E		SMM	
NUMBER OF MODULES	6		6		11		8		6		5	
UNIT	kg	(lb)	kg	(lb)	kg	(lb)	kg	(lb)	kg	(lb)	kg	(lb)
Standard NRU	432	( 951)	432	( 951)	506	(1115)	506	(1115)	432	( 951)	432	( 951)
Standard Solar Array	84	( 186)	84	( 186)	84	( 186)	84	( 186)	84	( 186)	84	( 186)
Standard Adapter	<u>123</u>	<u>( 272)</u>	<u>123</u>	<u>( 272)</u>	<u>123</u>	<u>( 272)</u>	<u>123</u>	<u>( 272)</u>	<u>123</u>	<u>( 272)</u>	<u>123</u>	<u>( 272)</u>
Subtotal	639	(1409)	639	(1409)	713	(1573)	713	(1573)	639	(1409)	639	(1409)
Standard CDPI	287	( 633) <sup>(1)</sup>	288	( 633) <sup>(1)</sup>	530	(1166)	407	( 900) <sup>(1)</sup>	347	( 766) <sup>(1)</sup>	167	( 367) <sup>(2)</sup>
Standard GNS&C	164	( 361)	164	( 361)	328	( 722)	164	( 361)	164	( 361)	651	(1435) <sup>(3)</sup>
Standard Electrical	124	( 273)	124	( 273)	495	(1092)	248	( 546)	248	( 546)	124	( 273)
Standard HRPI	---	----	250	( 552)	250	( 552)	---	----	---	----	---	----
Standard Thematic Mapper	250	( 552)	250	( 552)	250	( 552)	---	----	---	----	---	----
Polution Monitor (Non-Std.)	---	----	---	----	250	( 552)	---	----	---	----	---	----
Add M.E. (Non-Standard)	78	( 173)	---	----	146	( 322)	432	( 953)	435	( 960)	631	(1392)
Non-Std. Module Structure	16	( 35)	---	----	29	( 64)	87	( 191)	87	( 192)	126	( 278)
Non-Std. Electrical	23	( 50)	---	----	42	( 93)	125	( 275)	126	( 277)	182	( 401)
Extra NRU Structure	---	----	---	----	<u>112</u>	<u>( 246)</u>	---	----	---	----	---	----
Subtotal	942	(2077)	1076	(2371)	2432	(5361)	1463	(3226)	1407	(3102)	1881	(4146)
Propulsion Module												
Std. Orb. Adjust Dry	232	( 511)	232	( 511)	232	( 511)	232	( 511)	232	( 511)	232	( 511)
Std. RCS Dry	44	( 98)	44	( 98)	44	( 98)	44	( 98)	44	( 98)	44	( 98)
Total Dry Weight	1857	(4095)	1991	(4389)	3421	(7543)	2452	(5408)	2322	(5120)	2796	(6164)
Orb. Adj. Propell. (1000 fps)	312	( 688)	334	( 737)	545	(1201)	412	( 908)	390	( 860)	470	(1035)
RCS Propellant	48	( 105)	50	( 111)	70	( 154)	59	( 130)	57	( 125)	65	( 144)
Launch Weight	2217	(4888)	2375	(5237)	4036	(8898)	2923	(6446)	2769	(6105)	3331	(7343)

- (1) Remove tape recorders.  
 (2) Remove entire wideband data system.  
 (3) Non-standard (two modules).

ORIGINAL PAGE  
OF POOR QUALITY

**Table 5-4. Effects of Standardization on Satellite Weight and Availability  
Satellite Design with Redundant Components Operated In An  
Orbital Resupply Mode, Typical Result**

Satellite Project	% Increase In Satellite Weight Due to Standardization (Overkill)	Satellite System Availability	
		Non-Standard	Standard
EOS-B	37	0.92	0.92
EOS-C	7	0.92	0.90
EOS-D	43	0.83	0.83
EOS-E	56	0.84	0.84

## 6. SATELLITE ACCOMMODATION

With the current performance of the Space Shuttle and each satellite having a propulsive  $\Delta V$  of 304.8 m/sec (1000 ft/sec), the performance required of the Space Shuttle never exceeded its capability. The Space Shuttle deployed, retrieved, or serviced the EOS satellites in an elliptical orbit with 185 km (100 nmi) perigee and apogee corresponding to the final circular orbit altitude into which the satellite deployed itself. In the accommodation analysis, the satellite weight load factors were calculated for each type of flight and the costs of the user charged for transportation according to the assumptions and charge formulas shown in Table 6-1. Transportation charges were included for satellite support and adapters. For on-orbit resupply, transportation charges were also made for the flight support system accomplishing the module exchange on orbit. The flight support system weight was 1179 kg (2600 lb).

Table 6-1. EOS Transportation Charges

● ASSUMPTIONS

- / \$10.97M PER SHUTTLE FLIGHT DIVIDED EQUALLY BETWEEN UP AND DOWN FLIGHTS
- / UP FLIGHTS ARE SHARED
  - CHARGE PROPORTIONAL TO WEIGHT LOAD FACTOR
  - FULL CHARGE FOR 0.6 WEIGHT FACTOR
- / DOWN FLIGHTS ARE NOT SHARED
- / FLIGHT SUPPORT SYSTEM WEIGHT CHARGED TO PAYLOAD ON SATELLITE DEPLOYMENT FLIGHTS
- / MODULE EXCHANGE MECHANISM WEIGHT PLUS FLIGHT SUPPORT SYSTEM WEIGHT CHARGED TO PAYLOAD ON SERVICE FLIGHTS

● CHARGE FORMULAS:

SATELLITE DEPLOYMENT CHARGE:

$$\frac{\text{Satellite Wt} + \text{FSS Wt}}{\text{Shuttle Capability}} \times \frac{1}{0.6} \times \frac{\$10.97\text{M}}{2} = \text{Up Flight Charge}$$

UP SERVICE CHARGE:

$$\frac{(\text{Module Wt} \times \text{No. of Modules}) + \text{Prop. Module Wt} + \text{MEM Wt} + \text{FSS Wt}}{\text{Shuttle Capability}} \times \frac{1}{0.6} \times \frac{\$10.97\text{M}}{2} = \text{Up Flight Charge}$$

## 7. SYSTEM COSTING

System cost estimates for DDT&E, unit costs, and operating costs were made by application of the BRAVO cost estimating capability (see Reference 11.1, Section 11). The outputs of the cost estimates utilizing the computer program are tabulated in the BRAVO/EOS Workbooks on file at Aerospace Corporation.

## 8. RISK AND LOGISTICS ANALYSIS

Please refer to the section on Definition of Terms (Section 2) for definitions of the three logistics modes studied for this report.

The assumptions used in the risk and logistics analysis are:

1. Each satellite module for one satellite is treated as an average quantity; that is, each module has average reliability characteristics, average module costs for refurbishment, and average module weight for transportation.
2. When component wearout is expected for any component within a module, one of the following actions is taken:
  - (a) For the space resupply mode of operation, the module subject to wearout is replaced on orbit, returned, and refurbished on the ground.
  - (b) For the ground refurbishment mode, the satellite is replaced on orbit by one of the ground spare satellites.
  - (c) For the expend mode, the satellite is replaced by a new satellite.
3. For the space resupply mode, when component wearout is anticipated on the non-replaceable unit (NRU), the component is replaced during NRU refurbishment when the satellite is returned to the ground because of a failure within the NRU.
4. Where component wearout is encountered in mission equipment and tape recorders at four years.
5. The following logistic parameters were used as baseline values in the analysis. The value changes from the baseline only when sensitivity analyses are run.
  - (a) Satellite refurbishment time is six months.
  - (b) Satellite module cost is 39 percent of the unit cost

- (c) Shuttle/EOS operations occur in the 1982 through 1990 time frame. The analysis using the STS assumes the Shuttle to be available at WTR in 1982. The analysis ends arbitrarily in 1990.
- (d) The delay time between satellite failure calling for the Shuttle launch and the actual satellite replacement or module replacement is two months.
- (e) Payload transportation costs are shared with other payload programs.
- (f) Payload transportation reliability is 0.907 for spacecraft with propulsive  $\Delta V$  and 0.935 for spacecraft with no propulsive  $\Delta V$ . Transportation reliability measures the rate of success for placing the payload in final orbit and operating it without encountering satellite infant mortality. The satellite infant mortality rate is six percent. The Shuttle abort rate is assumed to be 1/2 percent and the spacecraft  $\Delta V$  abort rate is three percent.
- (g) The number of spares required on the ground for each mission which has two satellites on orbit is shown in Table 8-1. For each mission with one satellite on orbit, one spare satellite was assumed as a ground spare.

The detailed printouts from the Risk and Logistics Computer Program Analysis are in the BRAVO/EOS Workbooks on file at Aerospace Corporation. The findings of these analyses and top-level numerical results are presented and discussed in the next section on economic analysis and study findings.

**Table 8-1. Risk/Logistics Analysis Assumptions**

- **NUMBER OF SPARES REQUIRED ON THE GROUND FOR EACH MISSION WHICH HAS TWO SATELLITES ON ORBIT**

Mode Of Operation	Satellite Component Redundancy Level	
	None	One Level
Ground Refurbish	2 Satellites	1 Satellite
On-Orbit Resupply	1 Satellite + 1 Set of Modules	1 Satellite

## 9. ECONOMIC ANALYSIS AND STUDY FINDINGS

In this study, initial tradeoffs were accomplished in the study period through October 1974. The numerical results of these initial tradeoffs analyses are contained in the BRAVO/EOS Workbooks on file at Aerospace Corporation. The findings were:

1. Satellite propulsion capability tradeoffs - The satellites were designed with propulsive capability for 0, 304.8, and 457.2 m/sec (0, 1000, and 1500 ft/sec). For the satellites with propulsive  $\Delta V$  capability, the Shuttle deployed, retrieved, or serviced the satellite in lower energy orbits. The addition of propulsion to the satellite increased the satellite costs but decreased the transportation charges. The net effect made little difference in the system costs for the same mode of operation. Space resupply is the lowest cost mode of operation independent of satellite propulsive capability.
2. In order to be compatible with the Delta launch vehicle, for the EOS-A and EOS-B satellite designs satellite self-propulsion could not be used because of the payload weight performance capability of the Delta. However, this made the design incompatible with the Titan launch performance when the Titan launch vehicle had no upper stage. The Delta launch vehicle weight constraint had no margin available for satellite component redundancy.
3. The compromise design approach selected for further study used the satellite propulsion capability of 304.8 m/sec (1000 ft/sec) because of the compatibility with Titan and therefore all missions in the mission model. Payload deployment and rendezvous occur in an elliptical orbit with the Shuttle.
4. The results of the component comparison of the modes of operation with no satellite component redundancy for the EOS-B satellite system are shown in Table 9-1. It is shown that space resupply lowers the system costs significantly, first because of fewer launches over the nine-year operating period, and second because there is less satellite hardware refurbished.

**Table 9-1. Comparison of EOS-B Satellite System Modes of Operation  
STS Supported, No Satellite Component Redundancy**

<b>Satellite Operational Mode</b>	<b>System Availability</b>	<b>Number Of Satellite Launches</b>	<b>Cost To Establish and Operate Relative To Expendable Mode</b>
Expendable	0.75	18.1	1.00
Ground Refurbishable	0.75	18.1	0.60
Space Serviceable	0.78	14.3	0.43

● **SPACE SERVICING CAN LOWER THE SYSTEM COSTS SIGNIFICANTLY**

/ **FEWER LAUNCHES IN NINE-YEAR PERIOD**

/ **LESS HARDWARE REFURBISHED**

5. The tradeoff for component redundancy level on the satellite designs compared satellites with no component redundancy, one level of component redundancy, and two levels of component redundancy. All satellite designs had either backup capability or sufficient reliability to avoid single path failures in areas critical to satellite recovery. The results of the tradeoffs that used one level of component redundancy reduced system costs significantly since the transportation cost reduction exceeded the increased satellite DDT&E and unit costs. For two levels of component redundancy, the system costs increased over one level of redundancy since the satellite cost increases exceeded the transportation cost savings. Therefore, the one level of component redundancy approach was selected for standardized EOS module design in the succeeding effort.

Based on the initial findings described above, many of the alternative design concepts were eliminated. For the remainder of the study, the analysis concentrated on satellite designs with one level of component redundancy and a satellite propulsive  $\Delta V$  capability of 304.8 m/sec (1000 ft/sec). The issues remaining to be investigated were the influence of satellite subsystem standardization on the preferred mode of operation, the estimation of the cost savings available for the EOS programs with the optimum design approach, and the sensitivity of the study results to assumptions and system parameters.

The study of the influence of standardization was approached assuming that the maximum benefits would be obtained from standardization by assuming a single cognizant office using the same contractor set up for development and manufacture of all satellite configurations in a manner similar to the current launch vehicle systems. It was assumed that five programs (EOS-B, -C, -D, -E, and SMM) would share the DDT&E costs for all standardized spacecraft modules and elements for the standardized spaceframe. The standardization philosophy provided for standard modules, each containing exactly the same hardware

with the exception that hardware could be removed if not needed for a specific application (e. g. , tape recorders). The designs resulting from the application of this stabilization approach resulted in standardized spacecraft weights which were substantially larger than the custom design satellites. This overkill is shown in Table 5-4 (Sec. 5) for the EOS satellites. The system availability estimated for non-standard and standard satellite systems is also shown in Table 5-4. The influence of standardization on system availability is small.

The findings resulting from the analysis of standard and non-standard spacecraft for EOS are:

1. The percent savings due to standardization are shown in Table 9-2. Even though it costs more to develop the standardized spacecraft modules originally, the savings to each individual program are substantial, varying from 34 to 56 percent.
2. For the standardized satellites, substantial savings are shown for space resupply on each project relative to ground refurbishment or the expendable mode of operation (see Table 9-3). The EOS-B system saves by reducing the transportation costs with fewer flights and a reduction in satellite hardware costs. For space resupply less satellite hardware is refurbished than for ground refurbishment. Ground refurbishment saves relative to the expendable mode of operation by a reduction of investment in new satellite units. For EOS-C, -D, and -E, there is not a meaningful reduction in satellite transportation costs with space resupply. All of the savings are a result of reduced satellite hardware costs. A breakdown of the cost comparisons into satellite system cost categories is shown in Table 9-4.
3. The savings with non-standard satellites is very similar to the savings with standard satellites for the space resupply mode of operation (see Table 9-5).

**Table 9-2. Effects of Standardization on Cost, Satellite Design With Redundant Components Operating In An Orbital Resupply Mode, Typical Result**

Satellite Project	% Savings Due To Standardization DDT&E Cost	% Savings Due To Standardization Peak Annual Costs
EROS (EOS -A, B)	50	45
EOS -C	54	65
EOS -D	36	33
EOS -E	36	38

Table 9-3. Comparison of Satellite System Modes of Operation  
STS Supported, Standardized Satellites With Redundant  
Components

Satellite Project	Satellite Operational Mode	System Availability	Number Of Satellite Launches	Cost To Establish & Operate Relative To Expendable Mode
EOS-B	Expend	0.90	9.4	1.00
	Ground Refurb.	0.86	9.3	0.76
	Space Resupply	0.92	6.6	0.57
EOS-C	Expend	0.92	5.7	1.00
	Ground Refurb.	0.90	5.6	0.74
	Space Resupply	0.90	6.5	0.65
EOS-D	Expend	0.86	10.7	1.00
	Ground Refurb.	0.79	10.4	0.71
	Space Resupply	0.83	10.8	0.63
EOS-E	Expend	0.88	10.0	1.00
	Ground Refurb.	0.85	9.9	0.83
	Space Resupply	0.84	11.0	0.63

Table 9-4. Cost Comparisons (\$M), Space Resupply Mode vs Ground Refurbish Mode, Standardized Designs, One Level of Redundancy

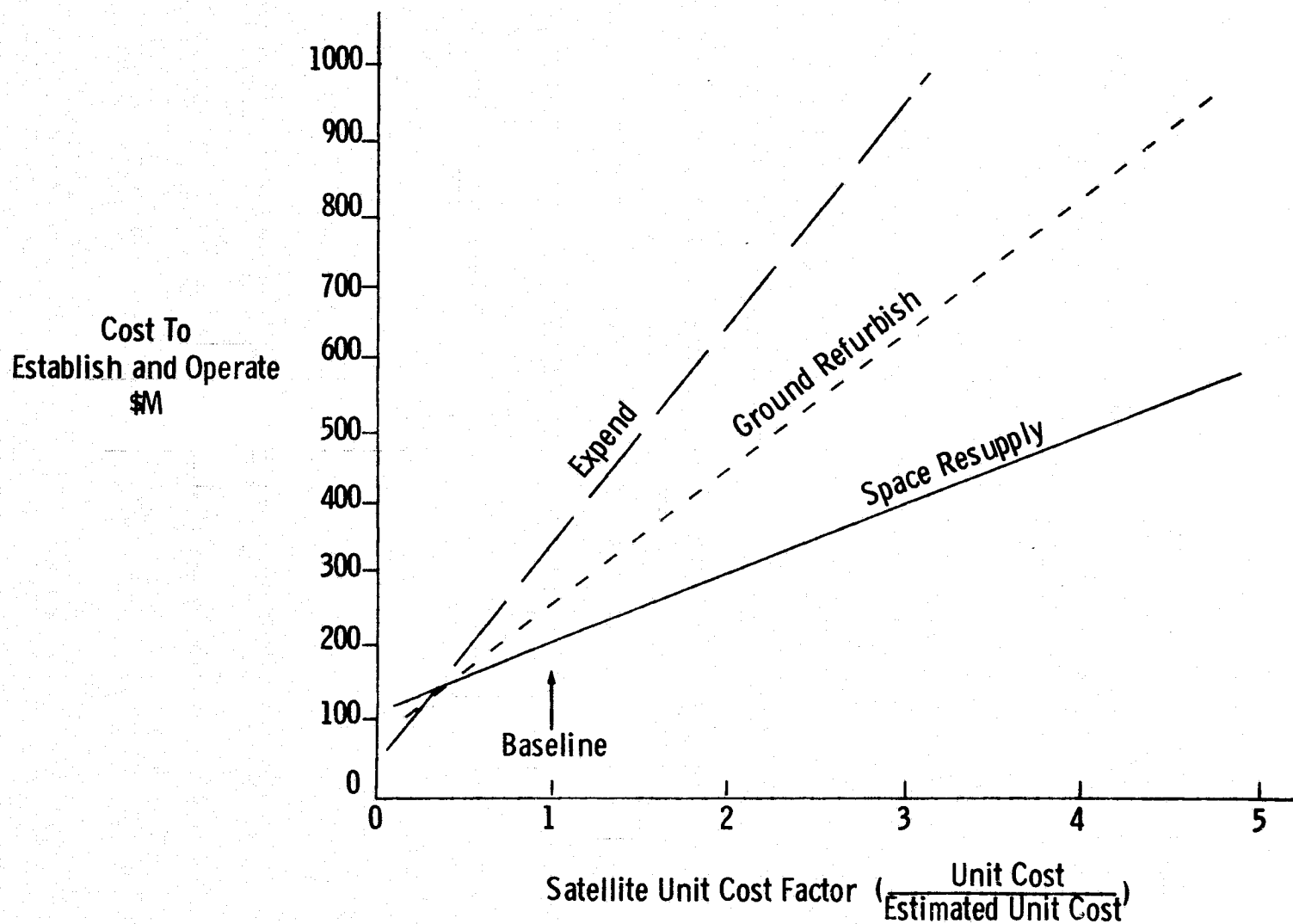
Satellite	Operational Mode	DDT&E	Investment	Transport	Maintenance	Operations	Total
EOS-B	Ground Refurb.	58	101	60	92	20	331
	Space Resupply	<u>58</u>	<u>101</u>	<u>38</u>	<u>49</u>	<u>14</u>	<u>260</u>
	Gr. Ref. - Sp. Resup.	0	0	22	43	6	71
EOS-C	Ground Refurb.	93	126	39	110	20	388
	Space Resupply	<u>93</u>	<u>126</u>	<u>53</u>	<u>58</u>	<u>23</u>	<u>353</u>
	Gr. Ref. - Sp. Resup.	0	0	-14	52	-3	35
EOS-D	Ground Refurb.	104	132	84	140	27	487
	Space Resupply	<u>104</u>	<u>132</u>	<u>80</u>	<u>98</u>	<u>28</u>	<u>442</u>
	Gr. Ref. - Sp. Resup.	0	0	4	42	-1	45
EOS-E	Ground Refurb.	91	158	74	118	24	465
	Space Resupply	<u>91</u>	<u>158</u>	<u>82</u>	<u>58</u>	<u>25</u>	<u>414</u>
	Gr. Ref. - Sp. Resup.	0	0	-8	60	-1	51

Table 9-5. Comparison of Satellite System Modes of Operation  
STS Supported, Non-Standard Satellites With Redundant  
Components

Satellite Project	Satellite Operational Mode	System Availability	Number Of Satellite Launches	Cost To Establish & Operate Relative To Expendable Mode
EOS-B	Expend	0.90	9.4	1.00
	Ground Refurb.	0.86	9.3	0.74
	Space Resupply	0.92	6.6	0.54
EOS-C	Expend	0.92	5.2	1.00
	Ground Refurb.	0.93	5.1	0.77
	Space Resupply	0.92	5.6	0.60
EOS-D	Expend	0.86	10.7	1.00
	Ground Refurb.	0.79	10.4	0.71
	Space Resupply	0.83	10.8	0.64
EOS-E	Expend	0.88	10.0	1.00
	Ground Refurb.	0.85	9.9	0.74
	Space Resupply	0.84	11.0	0.60

4. The crossover point where a space resupply cost savings disappears would be where a satellite unit cost is less than half the \$30M EOS-B unit cost (see Figure 9-1).
5. The space resupply mode of operation is less expensive than either of the other modes independent of the satellite repair costs (see Figure 9-2). The savings for space resupply relative to expending satellites is less for the higher repair costs. For the ground refurbishment mode, it costs more to operate with refurbishment than to expend satellites on orbit if the average repair cost is 70 percent or more than the average procurement cost for a satellite unit. This results from transportation charges for satellite return exceeding the benefits of reduced satellite hardware costs through refurbishment.
6. Satellite replacement delay has a large influence on system availability (see Figure 9-3). It will be important to keep the satellite replacement delay time under four months to obtain availabilities of 80 percent with the EOS system.
7. Another satellite characteristic having a large influence on availability is the failure rate (see Figure 9-4). As the satellite failure rate goes up, not only do the system costs increase for all three modes of operation, but also the number of flights required for logistics increases (although at a lesser rate for the refurbishment mode of operation).
8. It is expected that the number of satellite flights for the space resupply mode of operation could be further reduced by designing the satellites with less equipment attached to the non-replaceable unit. For instance, future studies should consider the potential benefits of making the solar array unit replaceable on orbit and making as many of the mission equipment units subject to on-orbit removal and replacement as possible. This would reduce the number of non-replaceable unit failures in the operating life of the system and, therefore, the logistic transportation costs.

Figure 9-1. Effect of Satellite Unit Cost on Space Resupply Benefits For STS Supported EOS-B Standardized Satellite Design with Redundant Components



**Figure 9-2. Effect of Satellite Repair Cost on Space Resupply Benefits For STS Supported EOS-B Standardized Satellite Design With Redundant Components**

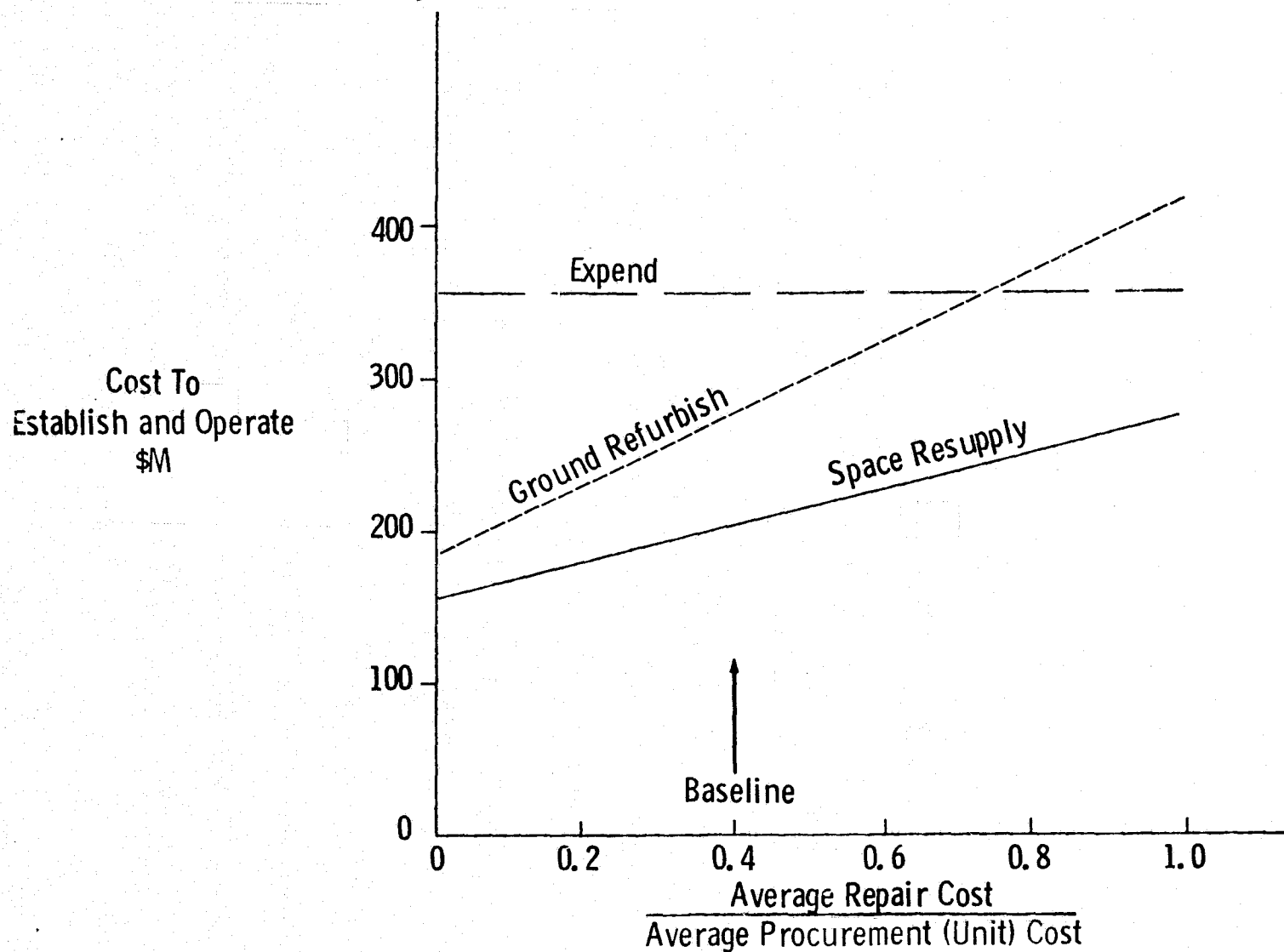


Figure 9-3. Effect of Launch Delay on System Availability  
Standardized Satellites, Redundant Components  
Space Resupply Mode of Operation

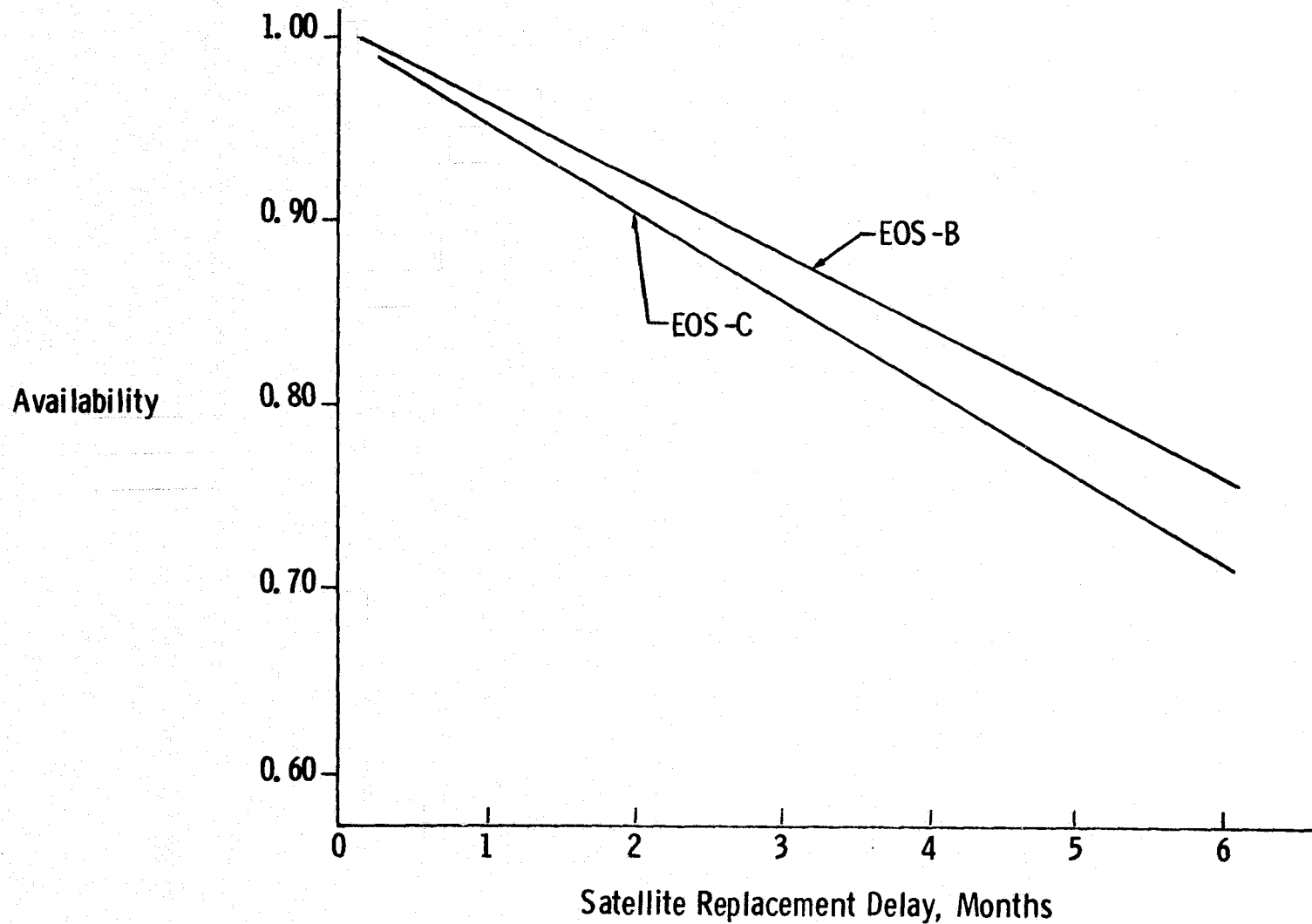
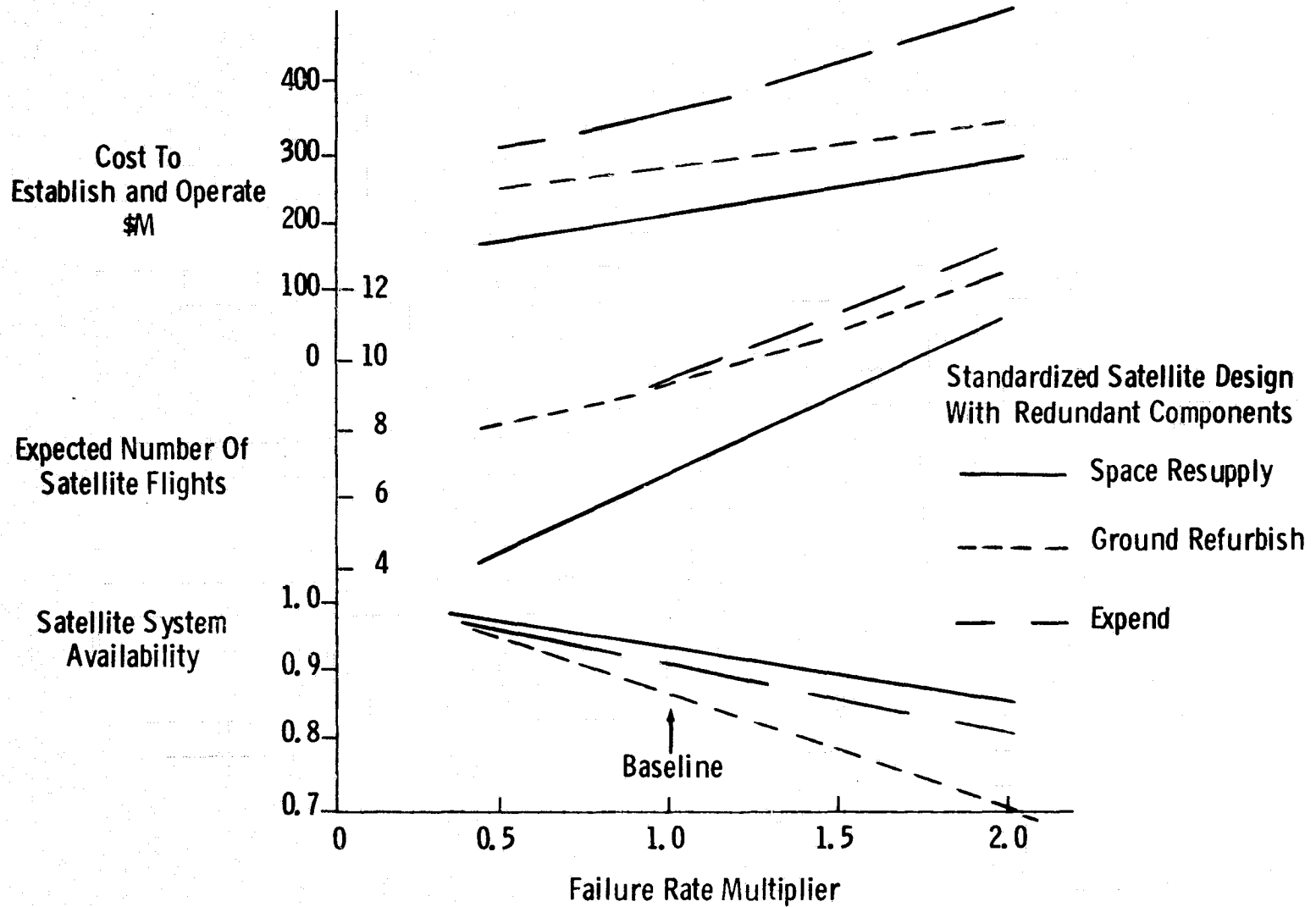


Figure 9-4. Effect of Satellite Failure Rate on Space Resupply Benefits For STS Supported EOS-B



Major findings for the EOS system resulting from this analysis are:

1. Space resupply significantly reduces costs to establish and operate over expending or ground refurbishing satellites. For the STS-supported standardized EOS-B the cost reduction is 23 percent over ground refurbishment and 43 percent over expending satellites.
2. Standardization of EOS-A, -B, -C, -D, -E, and SMM satellites (with common procurement and integration) significantly reduces DDT&E costs. For the EOS-A, -B, -C, -D, and -E projects, cost savings were 36 to 54 percent.

## 10. ADDITIONAL EFFORT

It is recommended that additional studies investigate the following:

1. The sensitivity of study results to transportation costs
2. The effect of EOS mission model changes on study results
3. The effect of low-cost design approach by applying low-cost design principals to the EOS satellites and applying the Aerospace cost/performance model to further optimize satellite designs.

## 11. REFERENCES

- 11.1 Shuttle User Analysis (Study 2.2) Final Report, Volume III: Business Risk and Value of Operations In Space (BRAVO), Parts 1, 2, 3, and 4, The Aerospace Corporation, ATR-74 (7342)-1, Vol. III, Parts 1, 2, 3, and 4 (30 September 1974).